INTERNATIONAL SOLDIER SYSTEMS CONFERENCE AND EXHIBITION 2004

Effect of fabric properties on Thermal Signature and Burn Injury

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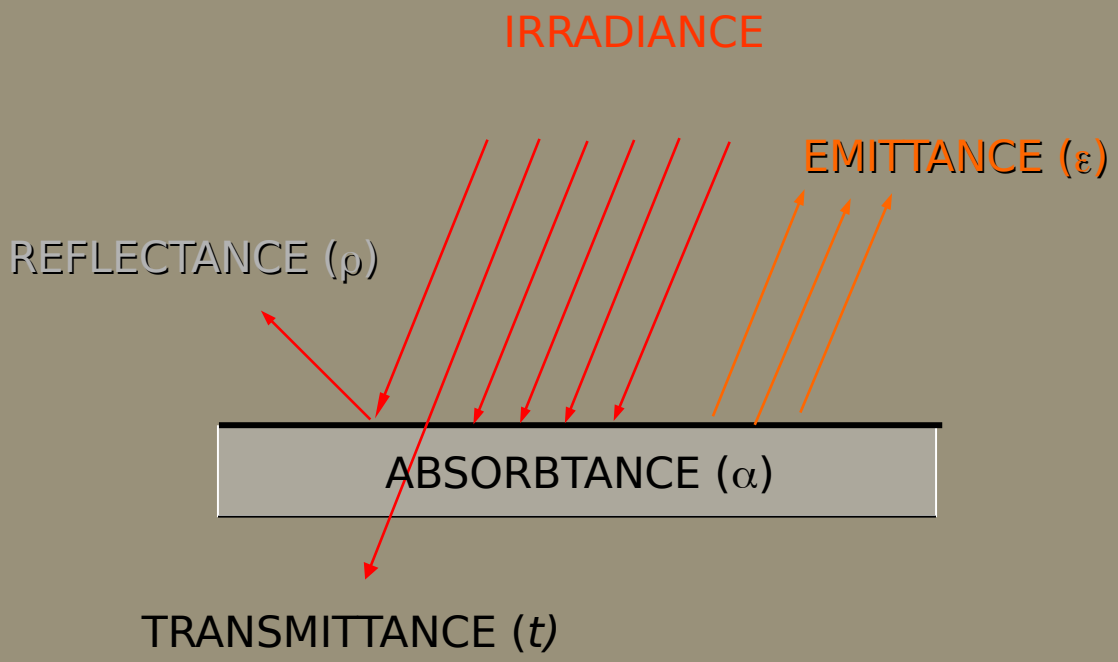
The Science Behind the Warrior: Yesterday, Today and

Abstract

Thermal signature reduction and flame/thermal protection are two Important protections for the survivability of the U.S. Soldiers operating on the battlefield. Thermal radiation is the most important parameter influencing the degree of both protections. In this study, extensive optical and physical properties are measured for various fabric materials and they are correlated with their burn injury and thermal signature data to identify controlling fabric properties. And the correlation provides design guidelines for military clothing to improve flame/thermal protection and thermal camouflage of future

Effects of Incident Radiation



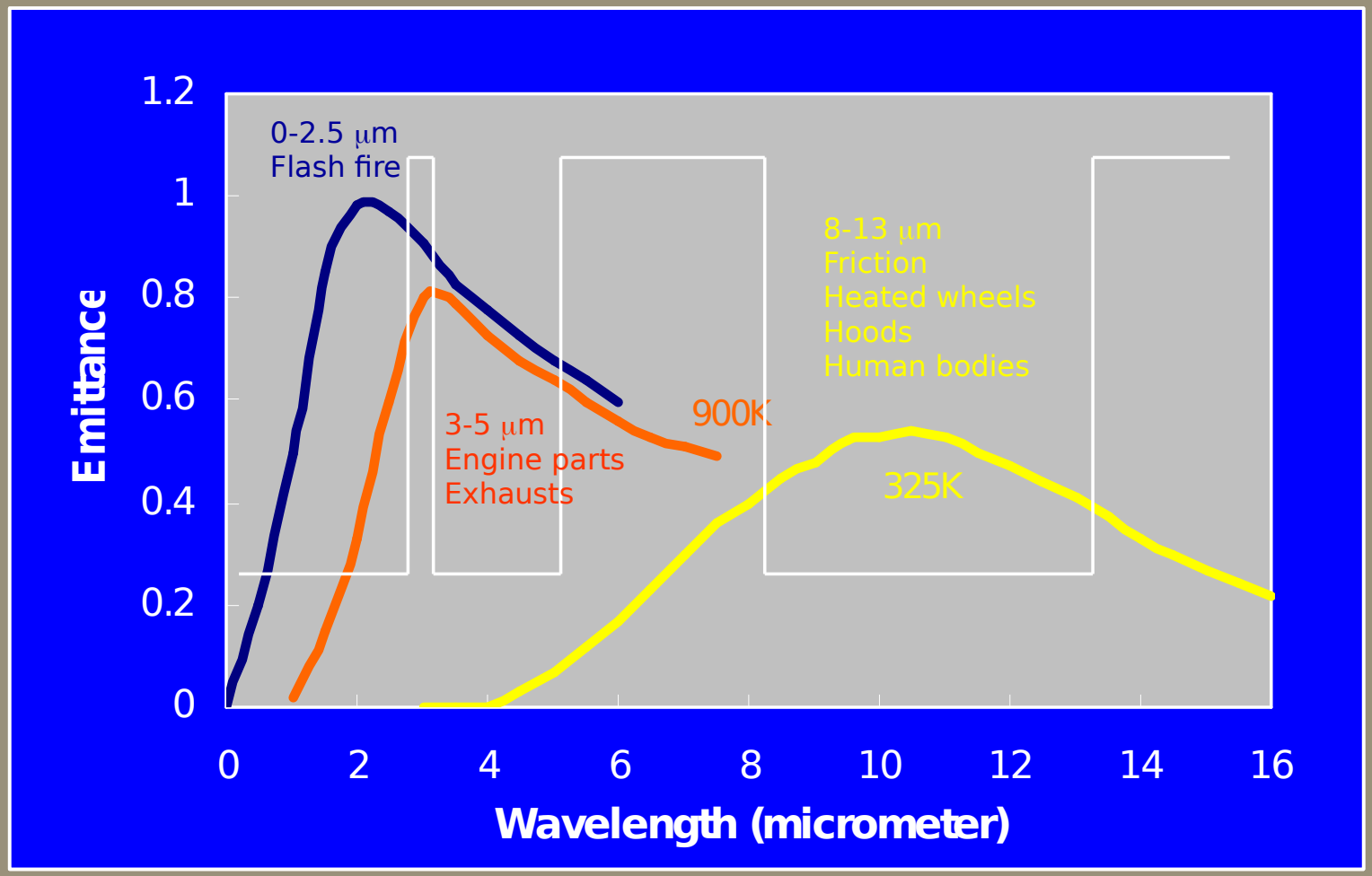
$\alpha + \rho + t = 1$

$\varepsilon = \alpha$ for steady state

If $t = 0$ then

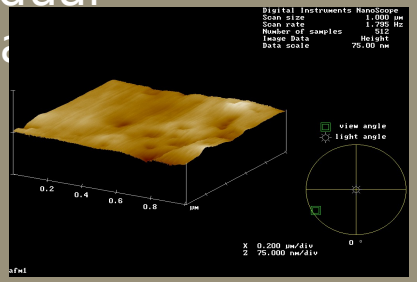
$\rho = 1 - \varepsilon$

Emittance Spectrum



Objective

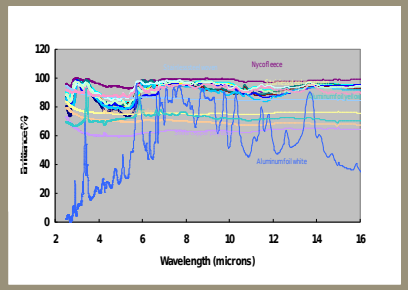
To investigate fabric properties as controlling parameters to improve flame/thermal protection and thermal signature camouflage of individual wa



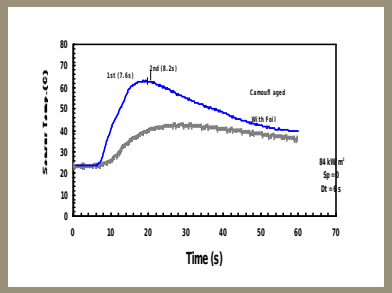
Physical Properties

Correlation

Thermal Image



Optical Properties



Burn Injury Data

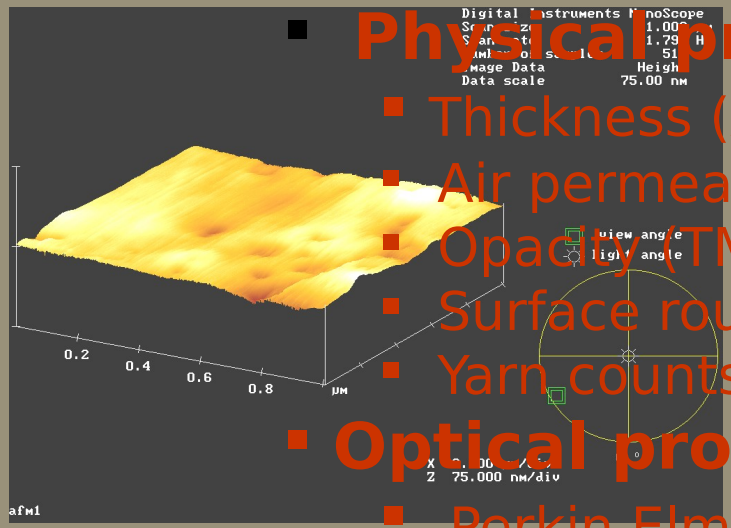
Implications/Significance: Scientific bases for evaluating and selecting military clothing fabrics. Guidelines for fabric material design and surface

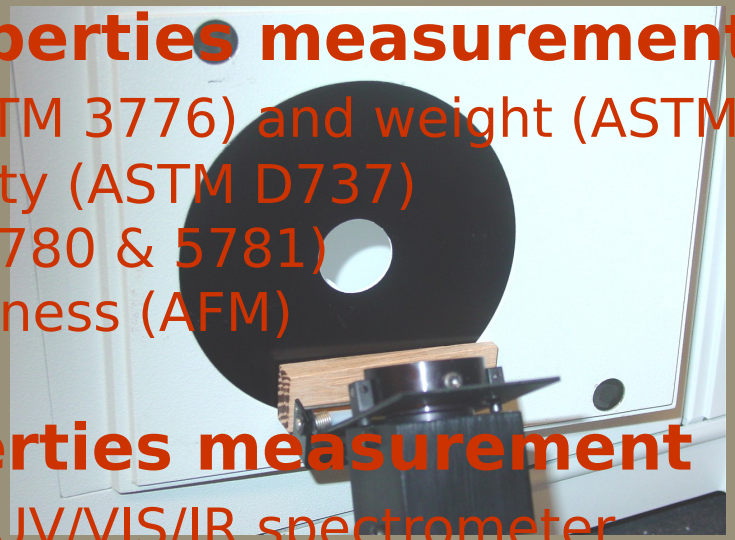
Approaches

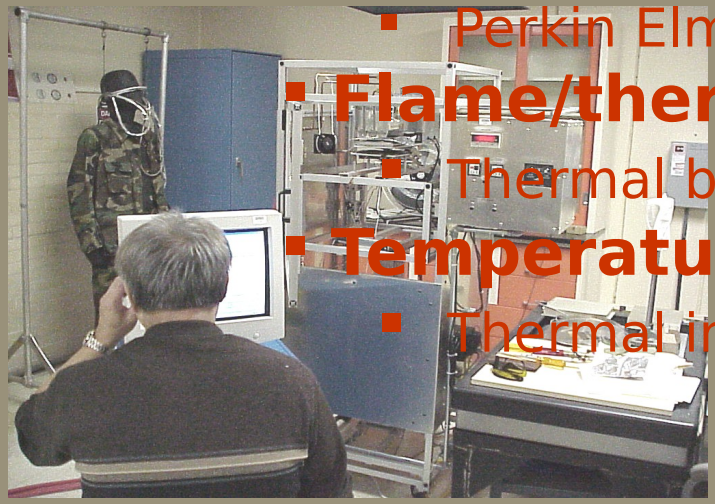
- **Thermal signature**
  - 18 samples (clothing fabrics, metal fabrics, and foils)
  - Optical properties in wavelength range 2.5 – 16 micron
  - Correlation of optical properties of the samples with their physical properties to identify controlling design parameters to improve thermal camouflage

- **Burn injury**
  - One single fabric (Nomex/Kevlar/P140)
  - Two major parameters (four different colors and two different constructions)
  - Optical properties in wavelength range 0 – 2.5 micron
  - Correlation of optical properties of the samples with their physical properties to investigate the effect of c and construction on their fire protective performance

Methods







- **Physical properties measurement**
  - Thickness (ASTM 3776) and weight (ASTM D17
  - Air permeability (ASTM D737)
  - Opacity (TM 5780 & 5781)
  - Surface roughness (AFM)
  - Yarn counts
- **Optical properties measurement**
  - Perkin Elmer UV/VIS/IR spectrometer
  - Perkin Elmer FTIR spectrometer
- **Flame/thermal protective performanc**
  - Thermal barrier test apparatus (TBTM)
- **Temperatures in thermal images**
  - Thermal image camera

Materials

Fabric samples

Sample		Fabric	Construction	Color
Clothing Fabrics	NCT	Nyco	Twill	Black
	NCE	Nyco	Denim	Blue
	NCU	Nyco	Duck	Brown
	NCS	Nyco	Sateen	Black
	NCF	Nyco	Fleece	Dark Blue
	N1	Nylon	Laminated	Orange
	N2	Nylon	Plain weave	White
	N3	Warp/nylon	Oxford	Camouflage
	N4	Nylon	Ripstop	Black
	P1	Poly/wool	Garbardine	Dark green
	O3	Poly/cotton	Quarpel	Black
Metal Fabrics	SSN	Stainless steel	Nonwoven	Gray
	SSW	Stainless steel	Woven	Gray
	NCN	Ni/Cu nylon	Nonwoven	Dark Gray
	SCN	Ag/Cu polyester	Nonwoven	Yellow
	NKW	Ni coated kevlar	Tight Weave	Tan
Foils	ALF	Aluminum Foil	Foil	Aluminum
	CUF	Copper Foil	Foil	Copper

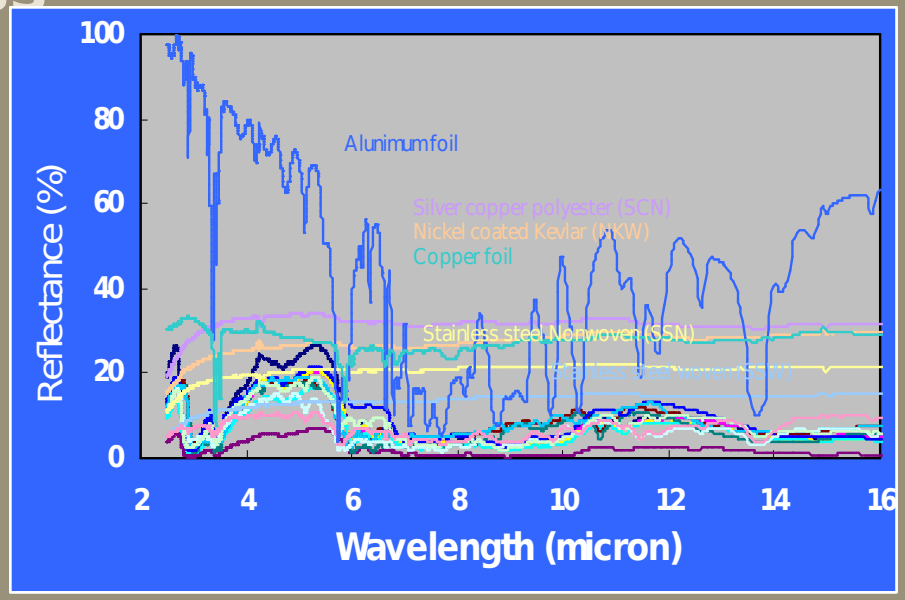
Results

Fabric characterization

Sample	Thickness (inches)	Weight (Oz/yd^2)	Air perm. (CFM)	Surface roughness	Opacity	
					TM 5781	TM 5780
Twill, Nyco (NCT)	0.024	10.1	13.0	5.844	0.475	5.020
Denim, Nyco (NCE)	0.032	13.7	8.9	11.233	0.948	80.840
Duck, Nyco (NCU)	0.025	11.6	6.9	9.515	4.970	63.140
Sateen, Nyco (NCS)	0.035	14.3	4.6	10.984	0.002	0.006
Fleece, Nyco, (NCF)	0.061	10.4	131.0	-	3.418	34.460
Laminated, Nylon (N1)	0.013	7.3	0.0	7.899	6.016	349.010
Plain, Nylon (N2)	0.011	3.6	10.6	5.602	181.021	1773.200
Oxford, warp/nylon (N3)	0.021	5.7	2.5	73.223	3.98	85.614
Ripstop, Nylon (N4)	0.005	2.3	11.9	10.944	49.880	1395.610
Garb, poly/wool (P1)	0.021	6.7	46.4	11.286	3.980	85.614
Quarpel, poly/cotton(O3)	0.015	7.0	3.4	28.025	0.085	5.348
Stainless steel (SSN)	0.062	10.1	860.0	8.454	948.812	Saturated
Stainless steel (SSW)	0.038	18.6	147.0	22.145	1007.410	Saturated
Ni/cu nylon (NCN)	0.021	1.6	488.0	12.459	555.425	Saturated
Ag/cu polyester (SCN)	0.015	1.8	707.0	6.140	1149.407	Saturated
Ni coated kevlar (NKW)	0.016	8.5	92.9	10.765	278.110	Saturated
Aluminum foil (ALF)	0.008	0.3	0.0	2.108	35.890	338.820
Copper foil (CUF)	0.008	0.4	0.0	6.146	35.589	328.610

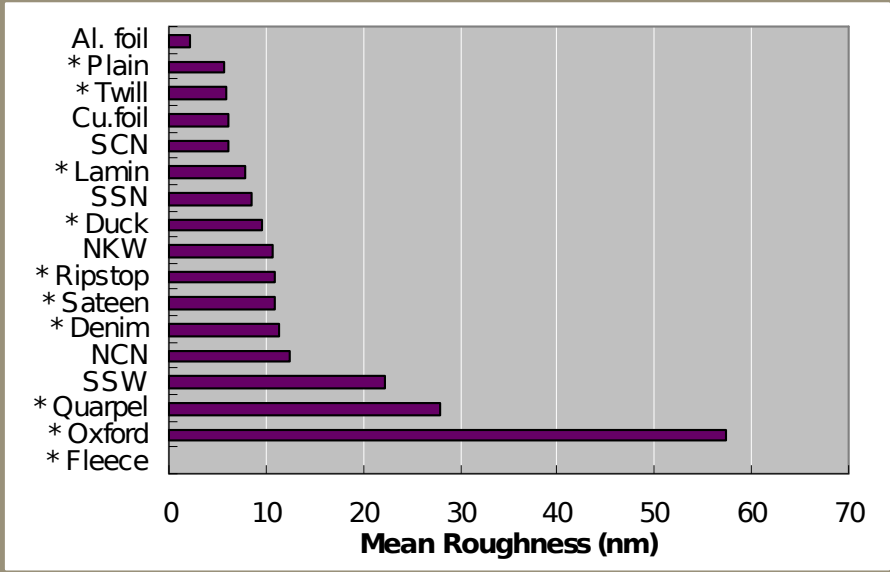
Correlation of Reflectance with Surface roughness

- The rougher the sample surface, the less it reflects



Aluminum foil
Silver copper polyester
Nickel coated kevlar
Copper foil
Stainless steel nonwoven

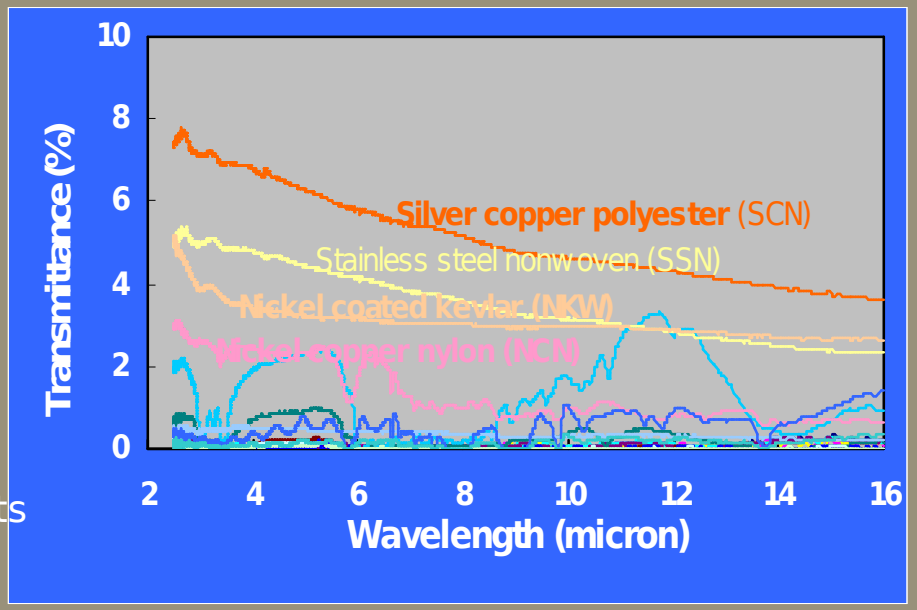
- More obvious correlation with metal fabrics or foils than with clothing fabrics



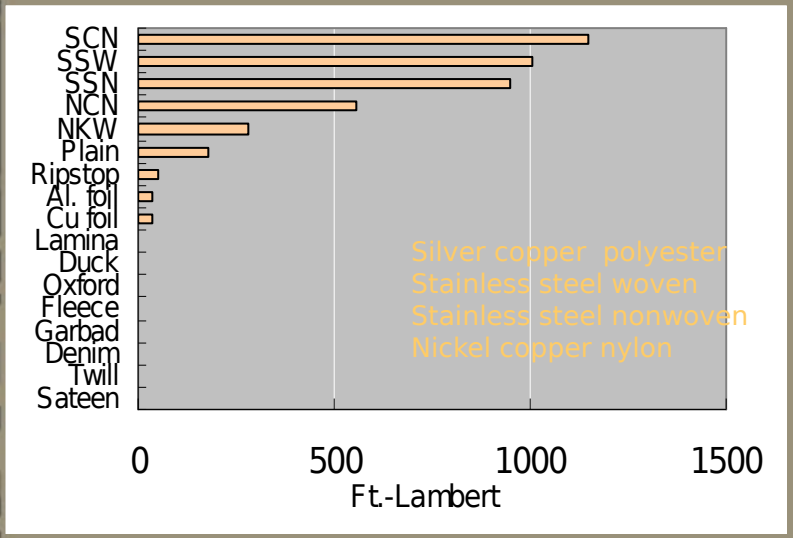
Aluminum foil
Copper foil
Silver copper polyester
Silver stainless nonwoven Nickel kevlar woven

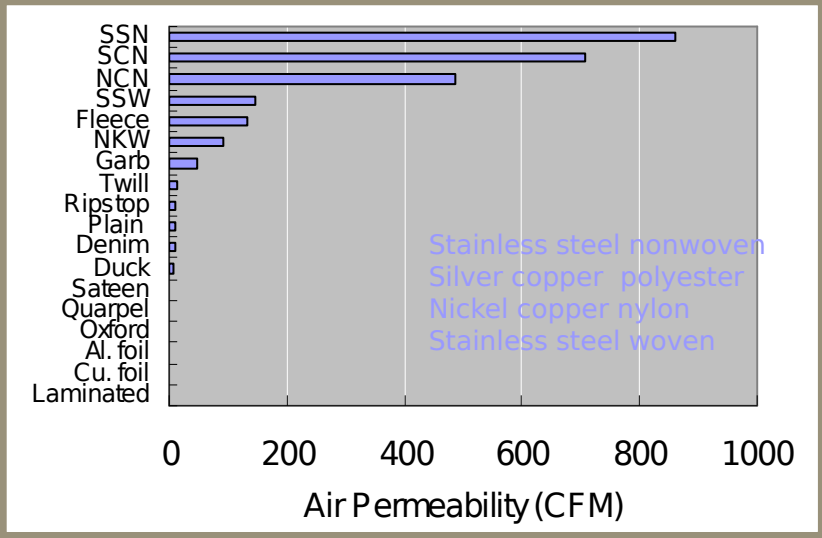
Correlation of transmittance with opacity and air permeability

- Metal fabrics with high opacity and air permeability showed more transmittance than foils and clothing fabrics.
- A nonwoven fabric shows higher transmittance than its Woven fabric.



Silver copper polyester
Stainless steel nonwoven
Nickel coated kevlar
Nickel copper nylon





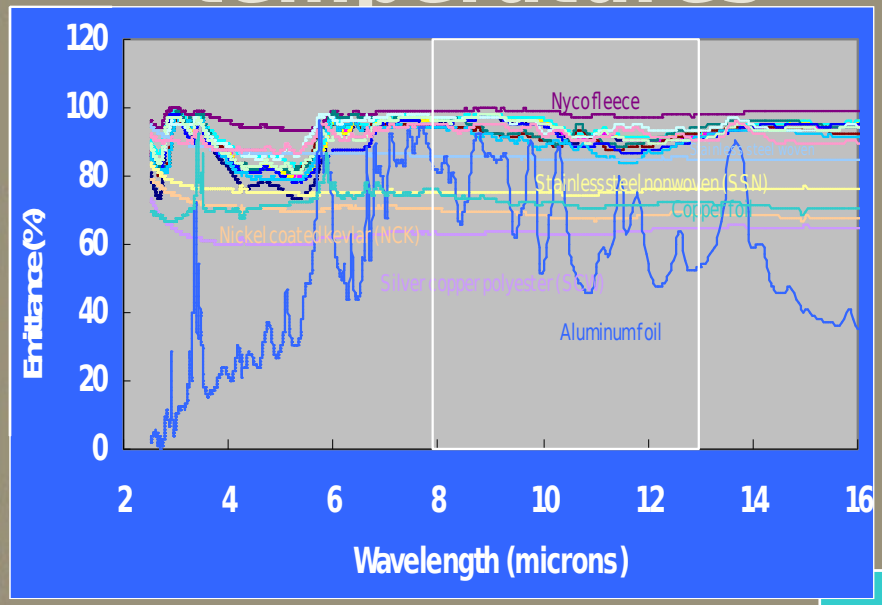
Thermal Image representing

Surface Radiance Temperatures

BDU BDU covered with Al. foil

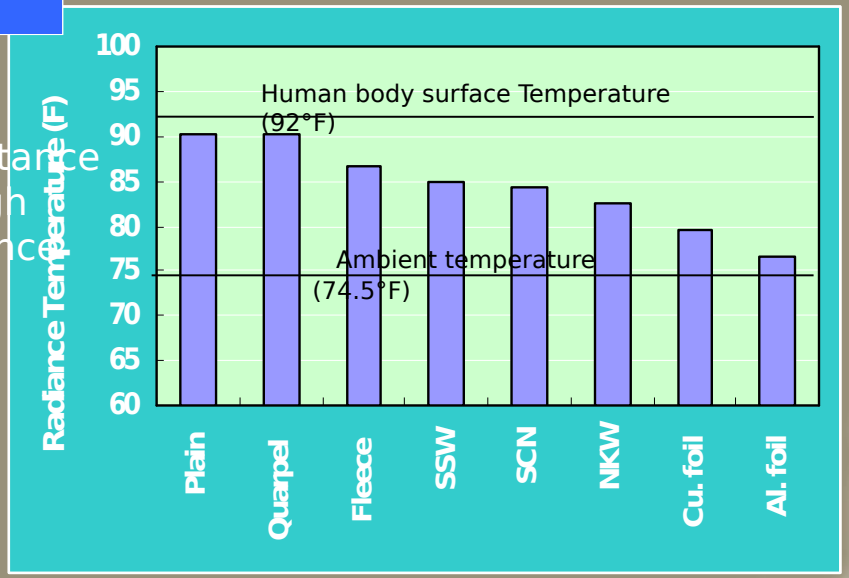
Thermal Images provided by a thermal image camera is
the representative of an “apparent radiance temperature ”

Correlation of emittance with surface radiance temperatures

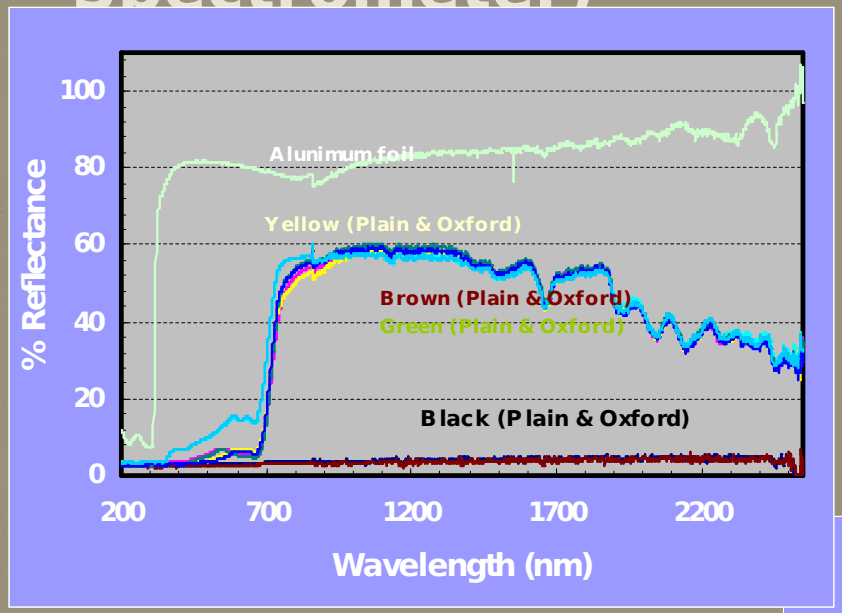


Aluminum foil
Silver copper polyester
Nickel coated kevlar
Copper foil
Stainless steel nonwoven

- Foils and metal fabrics showed low emittance and the clothing fabrics showed the high emittance and no differences in emittance among them
- Color was not an influencing factor for thermal signature



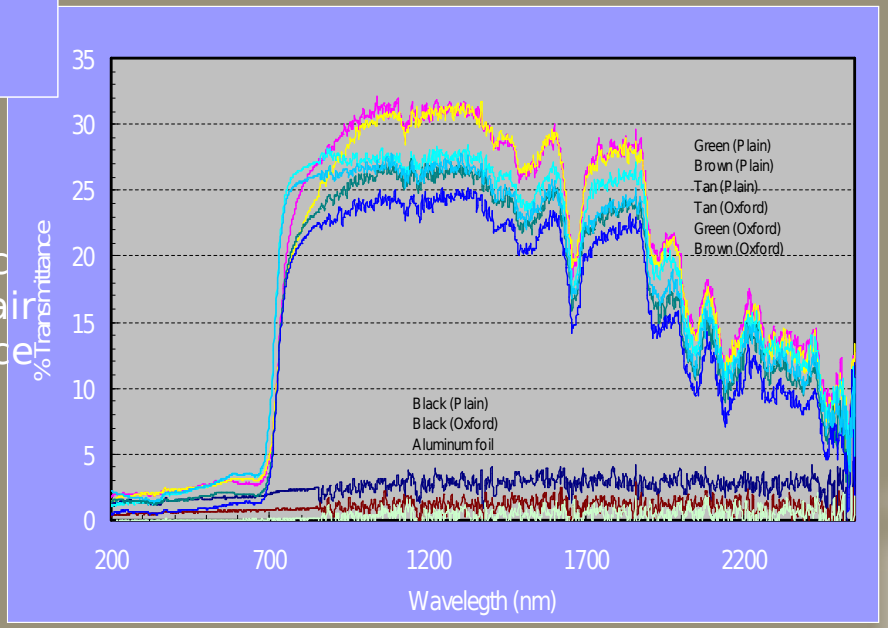
Optical Properties of Protective Clothing Fabric (0.2 – 2.5 micron, UV/VIS/NIR Spectrometer)



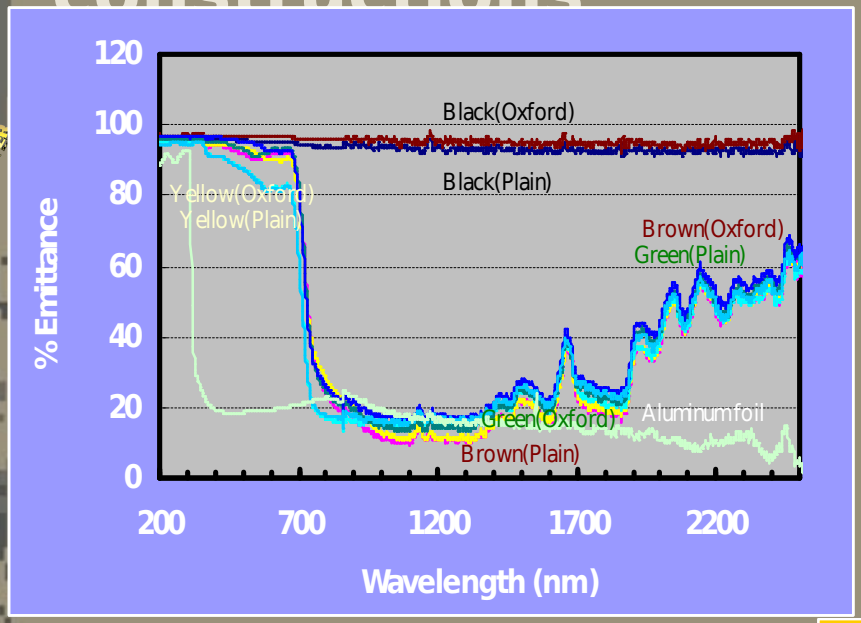
Lighter colored fabrics showed more reflectance than darker colors in the visible and near IR regions. Except aluminum foil,
the difference in reflectance among all others
is negligible

Transmittance was correlated with fabric construction. Plain weave with higher air permeability showed more transmittance than oxford weave.

Plain weave: 112 CFM
Oxford weave: 102 CFM

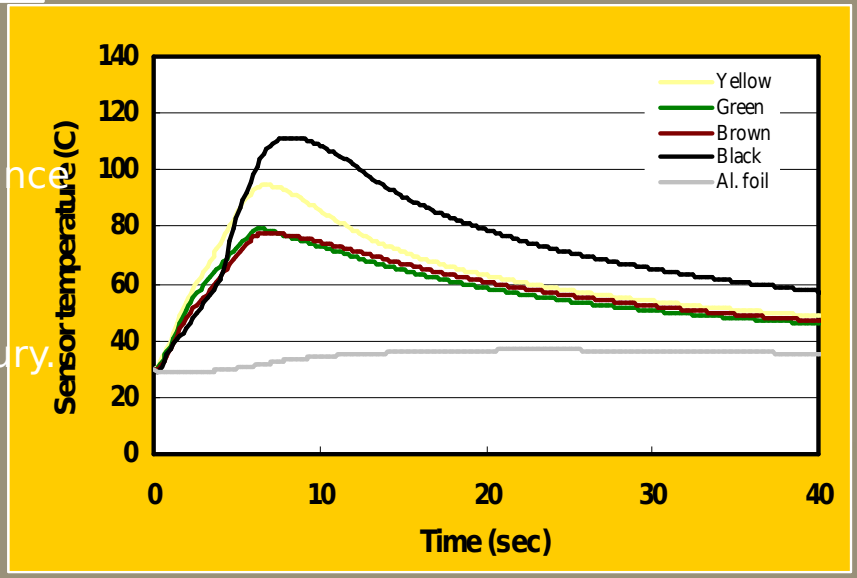


Emittance for different colors and constructions

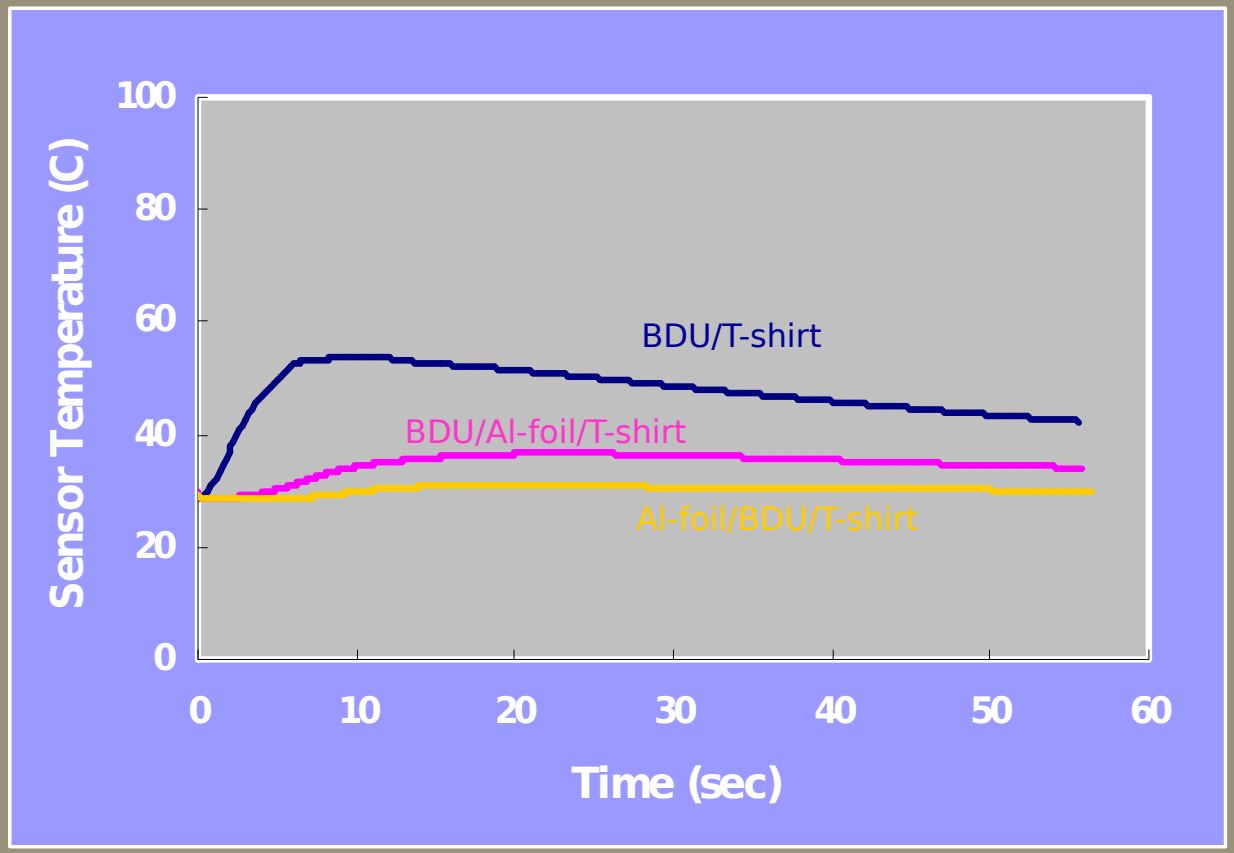


- Correlation was sensitive to the wavelengt range.
- More distinction among different colors wa in the near IR range.
- Aluminum foil was the only sample showin low emittance in both visible and near IR wavelength ranges.
- A fabric with black color showed much hig emittance than any other colors.

- Burn injury was more related with emittance than transmittance or reflectance
- Color was correlated with total energy absorbed, but not directly with burn injury.



Flame/thermal protective performance of Aluminum foil



Conclusion

- Color was not an major factor influencing both thermal signature
  and burn injury.
- Fabric construction with higher opacity and air permeability shows
  more transmittance.
- Emittance was more directly related with both burn injury and
  thermal signature than transmittance and reflectance.
- Low emittance resulting from high reflectance and low transmittance
  is a key to the improvement of fire protection and thermal camouflage
- Identification of controlling fabrics properties that